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SOIL QUALITY ASSESSMENT IN RAINFED COTTON GROWING ENVIRONS OF TWO AGROECOLOGICAL SUBREGIONS OF VIDARBHA, MAHARASHTRA

DHANASHREE PABLE[1], S. CHATTERJI[2],
M. V. VENUGOPALAN[3] & K. VELMOURGANE[4]

[1]*Research Scholar, ICAR- National Bureau of Soil Survey and Land Use Planning,*
Amravati Road, Nagpur, Maharashtra, India

[2]*Chairman of Students Advisory Committee & Principal Scientist, ICAR- National*
Bureau of Soil Survey and Land Use Planning, Amravati Road, Nagpur, Maharashtra, India

[3]*Principal Scientist, ICAR- Central Institute for Cotton Research (CICR), Nagpur, Maharashtra, India*

[4]*Scientist, ICAR- Central Institute for Cotton Research (CICR), Nagpur, Maharashtra, India*

ABSTRACT

Soil quality is a measure of soil's fitness to support crop growth without becoming degraded or otherwise harming the environment. Soil quality integrates the physical, chemical and biological, components and processes of soil with its surroundings. The present study was undertaken in soils of two major cotton growing agroecological subregions (AESR) of Vidarbha region of Maharashtra, India namely, AESR 6.3 and AESR 10.2. Twelve profiles were identified for determining physical, chemical and biological indicators of soils. Minimum dataset approach was adopted for determining soil quality indicators of the study areas. Two stage screening for minimum dataset identification was done using Pearson's correlation matrix of soil variables in respect of cotton yield followed by principal component analysis (PCA). The SQI was computed for each pedon based on the thirteen soil properties obtained from five principal components which had eigen values > 0.9 and were able to explain > 85 % variation. The SQI was found to be the highest in pedon 3 (1.63) from AESR 6.3 and pedon 12 (1.85) from AESR 10.2. The successful application of this method provides us to suggest that whenever we have such datasets, we could use this method for reliably assessing and monitoring soil quality for similar agroecological setups.

KEYWORDS : Agroecological Subregions, Cotton, Principal Component Analysis, Soil Quality

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Original Article

INTRODUCTION

Soil quality has been defined as the capacity of soil to function within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality and promote plant, animal and human health (Karlen et al., 1998 ; Carter et al., 1997). In context of agriculture, SQ is a measure of soil's fitness to support crop growth without becoming degraded or otherwise harming the environment (Acton and Gregorich,1995). SQ is thus a very important and significant concept with respect to agricultural production as well as its sustainability.

Soil quality assessment has been suggested as a tool for enhancing sustainability of soil and crop management practices. Hence, there is a need to develop criteria to evaluate soil quality and to take corrective

measures to improve it. Assessing SQ is relatively difficult because unlike water and air quality for which established standards are available in the form of legislation, soil quality assessments are purpose- oriented and site specific (Karlen et al., 1994). However, a quantitative assessment of soil quality could provide much needed information on the adequacy of the world's soil resource base in relation to the food and fiber needs of growing world population. SQ assessment typically includes development of minimum dataset (MDS) of SQ indicators and their quantification (Saybold et al.,1998) which reflect the capacity of any soil to function and is derived from educational studies or general quantitative observations of soil. A minimum dataset identifies locally relevant and mutually exclusive soil indicators and evaluates the link between selected indicators and significant soil and plant properties.

A minimum dataset identifies locally relevant and mutually exclusive soil indicators and evaluates the link between selected indicators and significant soil and plant properties. This dataset consists of a number of indicators describing the quality health of the soil. However, development of soil quality index has often taken into consideration only soil physical and chemical properties (indicators) in view of the availability of methods and tools to determine them. Biological properties have very rarely been used in developing soil quality index as it is relatively difficult to measure / predict biological behavior of soils. However, of late, it is being appreciated that SQ is an integrated concept encompassing broad range of physical, chemical and biological properties that can be used to assess its quality. Although it is useful to examine these properties individually, soil should be viewed as an integrated system. Physical and chemical properties are shaped by biological activity, and biological activity is enhanced or limited by physical and chemical conditions (Rao and Manna, 2005).

The relatively recent approach to development of MDS of SQ indicators involves the use of a statistical technique, namely, Principal Component Analysis (PCA). PCA has been widely employed as an approach to acquire MDS for SQ assessment. Through PCA analysis, the number of independent soil parameters could be reduced and the problem of multi-colinearity could be solved to some extent (Guilin et al., 2007). PCA was employed as a data reduction tool to select the most appropriate indicators of site from the list of indicators generated in Pearson correlation coefficients methods (Rezaei et al., 2006).

Cotton is an important fibre and cash crop grown widely in the tropical and subtropical regions of the world. The major states growing cotton in the country in 2013 in order of hectarage were Maharashtra (4.13 m ha or 40% of the total cotton growing area in the country) representing almost half of the total area growing cotton in India in 2012, followed by Gujarat (2.36 m ha or 20%) and Andhra Pradesh (2.14 m ha or 16%). The production and productivity of cotton in Maharashtra, during 2012-13 was 80.0 lakh bales and 329 kg/ha respectively (CCI, 2013). An agroecological region (AER) that comprises homogenous set of natural physical environments, such as climate, soils and physiography (landform) often becomes a regional planning unit. The entire state of Maharashtra is categorized into four AERs, namely, AERs 6, 10, 12 and 19 (NBSS & LUP, 1992) that exhibit contrasting climate, soil and land use. Of these agroecological regions, 6 and 10 are the major cotton growing regions together accounting for 33.21 lakh ha (95.68 %) of the cotton area in Maharashtra (Anonymous, 2013). Agro-ecological subregion (AESR) 6.3, a finer subdivision of AER 6 is the dominant cotton growing sub-region and similarly AESR 10.2, a finer subdivision of AER 10 is the dominant cotton growing sub-region.

However, no systematic study has been undertaken on soil quality assessment for rainfed cotton ever before in the two AESRs. It would be, therefore, important as well as interesting to assess soil quality in the two cotton growing AESRs.

METHODS

Study Area

The study area constitutes cotton growing soils of different agroecological subregions (AESR) of Vidarbha region of Maharashtra, India, namely, AESR 6.3 and AESR 10.2 which constitute Akola district and Nagpur district region of Maharashtra, India respectively. Akola district (AESR 6.3) is situated at Deccan Plateau in between 20° 42' 11" N lattitude and 76° 59' 58" E longitude at an altitude of 285 m above MSL and has been classified under hot, moist semi-arid ecosubregion. Nagpur district is situated at Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range) in between 21° 09' 24" N latitude and 79° 05' 17" E longitude at an altitude of 339 m above MSL and has been classified under hot, dry sub-humid ecosubregion. Twelve cotton-growing sites, six in each district were selected for soil profile studies based on variation in soil depth. Information was collected from farmers on crop yield data and the yield considered for correlating it with soil quality index was average of three year, namely normal, worst and best years. Horizon-wise soil samples were collected for determining physical and chemical properties and for biological properties. Soil samples were analyzed for these properties using standard procedures.

Soil Quality Index

The methodology to determine soil quality index comprises of four main steps: 1) defining the goal, 2) selecting a minimum data set (MDS) of indicators that best represent soil function, 3) scoring the MDS indicators based on their influence on soil functionality, and 4) integrate the indicator score into a comparative index of soil quality.

The study was aimed to assess the soil quality of two cotton growing AESRs in terms of the capability of soil to produce cotton crops. Henceforth, cotton crop yield can be an important indicator of soil quality, because it serves as a plant bioassay of the interacting soil characteristics. The average yield of cotton computed on the basis of yield obtained from 2010 to 2013 (Table 1) were considered as goal; as the farmers like to get more consistent productivity from the unit land.

Table 1: Average Yield (Q/Ha) of Seed Cotton

Pedon No.	Year-Wise Yield (Q/Ha)			Average Yield (Q /Ha)
	2010-11	2011-12	2012-13	
AESR 6.3				
Pedon 1	19.9	17.1	22.4	19.8
Pedon 2	14.4	10.5	15.6	13.5
Pedon 3	28.0	25.9	33.1	29.0
Pedon 4	17.1	12.5	23.0	17.5
Pedon 5	19.7	18.7	27.9	22.1
Pedon 6	16.2	13.2	17.3	15.6
AESR 10.2				
Pedon 7	25.2	22	27.8	25.0
Pedon 8	26.3	26	28.7	27.0
Pedon 9	21.9	20.4	23.7	22.0
Pedon 10	30.2	28.4	35.9	31.5
Pedon 11	12.1	9.7	14.2	12.0
Pedon 12	36.8	29.8	38.4	35.0

The complete soil variable datasets were evaluated to develop a minimum data set through a series of unit as well as multivariate statistical methods using SPSS software version 11.5. Pearson's correlation matrix among average yield of cotton crop and soil properties were evaluated for initial screening of indicators. Mutually exclusive and locally relevant

parameters which are having significant correlation (two tailed test, $p<0.05$) with average yield were chosen for the next step in MDS formation. The standardized principal component analysis (PCA) was performed for each statistically significant variables (Chaudhury et al., 2005). The correlation matrix based initial screening was done prior to PCA so that the components of PCA can be evaluated in terms of our goal set-forth i.e. crop yield (as PCA doesn't take care of dependent variable). Principal components (PC) for a data set are defined as linear combinations of variables that account for maximum variance within the set by describing vectors of closet fit to the n observation in p-dimensional space, subject to being orthogonal to one another. The principal components receiving high eigen values and variables with high factor loading were assumed as the variables that best represent system attributes (Brejda et al., 2000). Therefore, only the PCs with eigen values 0.5 or greater, which explained at least 5% of the variation in the data were examined. Within each principal component, only highly weighted factors were retained for the MDS.

After determining the MDS indicators, each of the MDS variables was scored on the basis of the performance of soil function, considering soil type and variation of values within treatments. Each variable was transformed or standardized to a value between 0 (least favorable soil function) and 1 (most favorable soil function) scoring functions (Andrews et al. 2002). Once transformed, the MDS variables for each observation were weighted by using the PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage, divided by the total percentage of variation explained by all PCs with eigenvectors greater than 0.9, provided the weighted factor for variables chosen from the corresponding PC.

The final formula $SQI=\sum Wi\ Si$

where W is the PC weighting factor and S is the indicator score. Here, the assumption is that higher index scores meant better soil quality or greater performance of soil functions in terms of cotton crop growth.

RESULTS

The pedons under study showed (Table 2) variation in soil depth and were grouped under various categories viz., shallow (< 50 cm), moderately shallow (50-75 cm), moderately deep (75-100 cm), deep (100- 150 cm) and very deep (>150) as per Soil Survey Manual (Soil Survey Staff, 1998). In cotton growing soils of AESR 6.3, pedon 2 (43 cm) was shallow; pedon 6 (91 cm) was moderately deep; pedons 4 (143 cm) and 5 (120 cm) were deep; pedons 1 (150+ cm) and 3 (150+ cm) were very deep. In AESR 10.2, out of six cotton growing soils, pedon 11 (15 cm) and Pedon 9 (35 cm) were shallow; Pedons 10 (108 cm) and 8 (140 cm) were deep; pedons 7(150+ cm) and 12 (150+ cm) were very deep.

Table 2: Weighted Means of Soil Properties

Pedon No.	Depth (cm)	Clay	sHc (mm/hr)	EC (dSm^{-1})	OC (%)	Exchangeable Mg	Exchangeable K	CEC	BS %	SMBC (µg/g)	DHA (µg TPF g^{-1})	Nitrogen Mineralisation (kg /ha)	Shannon-Weaver Index (H')
AESR 6.3													
Pedon 1	150	59.34	1.34	0.34	0.35	20	0.5	43.1	96.5	65.92	2.98	22.82	0.55
Pedon 2	43	39.81	1.69	0.26	0.41	12.3	0.6	27.1	112.2	46.76	2.42	12.54	0.47
Pedon 3	150	60.84	3.23	0.17	0.31	13.9	0.8	48.9	102.8	40.97	2.04	18.82	0.44
Pedon 4	143	67.45	1.82	0.52	0.44	20.1	0.6	46.9	109	45.29	1.95	14.54	0.5
Pedon 5	120	65.98	2.4	0.23	0.45	17.5	0.8	52.6	110.4	58.22	1.93	26.27	0.57
Pedon 6	91	67.64	0.67	0.2	0.52	17.1	0.7	58.8	103.9	157.55	1.81	32.27	0.41
AESR 10.2													
Pedon 7	150	56.4	1.79	0.21	0.44	17.1	0.5	51.3	99.5	37.97	2.4	25.09	0.47
Pedon 8	152	60.37	1.54	0.22	0.31	22.5	0.7	53.1	103.9	62.9	3.73	38.99	0.65
Pedon 9	35	36.11	3.2	0.38	0.42	11.6	1.2	33.6	107.2	95.87	2.32	13.82	0.08
Pedon 10	108	64.81	1.8	0.18	0.36	11.4	0.5	54.5	107.9	41.86	5.05	25.68	0.43
Pedon 11	15	64.44	2.03	0.53	0.62	8.8	0.9	59.2	108	90.49	6.13	16.27	0.58
Pedon 12	150	66.71	2.85	0.18	0.48	15.8	0.4	57.9	112.5	157.78	2.55	32.72	0.36

3.1 Selection of Minimum Data Set (MDS) for Soil Quality Assessment: Pearson correlation matrix revealed 13 soil properties viz., depth, clay, sHC, EC, OC, exchangeable Mg, exchangeable K, CEC, BS %, SMBC, DHA, nitrogen mineralization and Shannon-Weaver index which are mutually exclusive and locally relevant having significant correlation (two tailed test, $p<0.05$) with yield. Hence, these 13 properties were subjected to Principal Component Analysis (PCA).

Table 3: Results of Principal Component Analysis (PCA) of Soil Quality Indicators of Statistically Significant Variable (P<0.05)

Component	PC1	PC2	PC3	PC4	PC5
Eigen Value	4.33	3.18	1.74	1.06	0.91
% of Variance	33.28	24.46	13.36	8.17	6.98
Cumulative %	33.28	57.75	71.11	79.27	86.25
Weightage	0.386	0.283	0.155	0.095	0.081

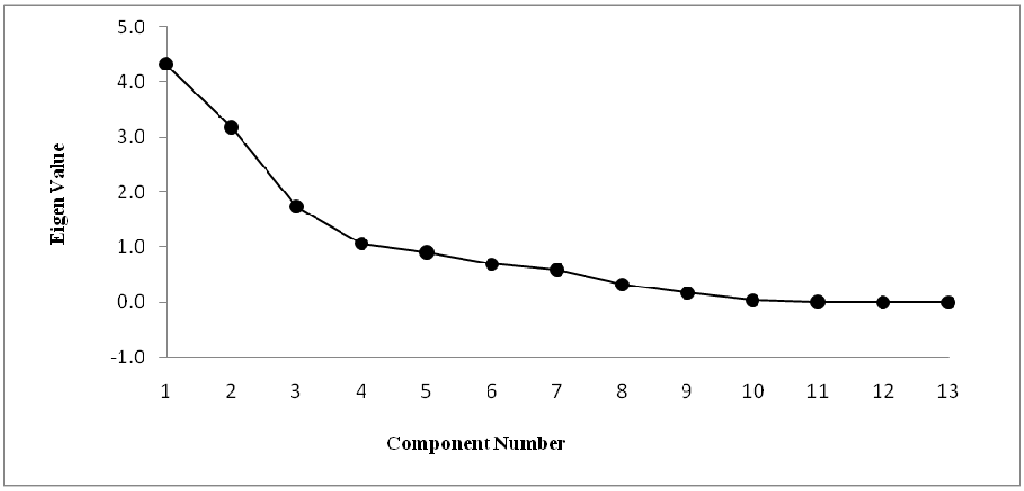

Figure 1: Scree Plot Obtained from PCA

PCA results show that first five PCs were able to explain more than 85% of the variability present in the dataset (Table 3). The scree plot (Figure 1) indicating component wise eigen value distribution also got flattened after fifth PC revealing negligible contribution of rest of the PCs towards the system variability. The final composition of MDS was made by taking into account the highly loading factors with respect to each component (Table 4).

Table 4: Factor Loading/ Eigen Vectors of PCA

Variable	PC1	PC2	PC3	PC4	PC5
Depth	0.878987	-0.35564	-0.01994	-0.0155	0.062576
Clay	0.711854	0.567662	0.103374	0.007309	0.027713
sHC	-0.53181	-0.32173	0.702422	0.161881	-0.06867
EC	-0.41581	0.46316	-0.624	0.19714	0.138765
OC	-0.31552	0.807918	6.32E-05	-0.39382	0.116352
Exchangeable Mg	0.790957	-0.23847	-0.37366	-0.11379	0.033573
Exchangeable K	-0.64794	0.084332	-0.14826	-0.07217	-0.42424
CEC	0.567084	0.658554	0.393832	-0.11538	-0.10007
BS %	-0.44904	0.093418	0.347232	-0.26157	0.718351
SMBC	-0.09012	0.877297	-0.08063	-0.23386	-0.23788
DHA	-0.16068	0.585988	0.333603	0.701809	-0.01839
Shannon-Weaver index	0.580204	0.368325	-0.21982	0.416448	0.273058
Nitrogen Mineralisation	0.743448	0.07556	0.489611	-0.14323	-0.16381

Higher factor loading soil variables considered for MDS were depth, clay, exchangeable Mg and nitrogen mineralization under PC1; OC and SMBC under PC2; sHc underPC3; DHA under PC4 and BS % under PC5. The result also revealed that the variables selected from PC1 is the most influencing soil quality indicators for the two AESRs as far as the cotton growing regions are concerned. Similarly, soil variables screened from higher component number achieved lesser weightage or vice-versa; as the variability encountered by an individual PC decreases with the increasing component number. Scoring of each of the MDS variables was on the basis of the performance of soil function, considering soil type and variation of values within treatments (Table 5).

Table 5: Scoring Chart for Selected Soil Variables Based on the Soil Type and the Variation of Values within the Pedons

Score	Depth (Cm)	Clay (%)	Saturated Hydraulic Conductivity (Mm/Hr)	Organic Carbon (%)	Exchangeable Magnesium	Base Saturation (%)	Soil Microbial Biomass Carbon (SMBC) (Mg/G)	Dehydrogenase Activity (DHA) (Mg TPF G^{-1})	Nitrogen Mineralisation (Kg/Ha)
0.1-0.25	<30	-	<1.5	0.2-0.4	>19	-	-	-	-
0.25-0.5	30-60	-	2-1.5	0.4-0.6	19-16	<60	-	<1.5	-
0.5-0.75	60-80	< 65	2.5-2	0.6-0.8	16-13	80-60	<45	3.5-1.5	<15
0.75-1	80-100	>35	3-2.5	0.8-1	13-10	100-80	65-45	5.5-3.5	35-15
1	>100	35-65	>3	>1	<10	>100	>65	>5.5	>35

Soil Quality Assessment

The MDS variables for each treatment were transformed by using scoring functions (Table 6). The SQI was calculated by using weightage for each scored MDS variable according to the formula as given in above (Methods)

In our case, SQI equation turned out to be

SQI = [0.386 *X* S (depth)] + [0.386 *X* S (clay)] + [0.155 *X* S (sHc)] +[0.283 *X* S (OC)] + [0.386 *X* S (exchangeable Mg)] + [0.081 *X* S (%BS)]+ [0.283 *X* S (SMBC)] + [0.095 *X* S (DHA)] + [0.386 *X* S (N mineralization)]

Table 6: Soil Quality Index (SQI) of Different Pedons Developed by PCA in the Two Aesrs

Pedon No.	Sqi	Pedon No.	Sqi
Aesr 6.3		Aesr 10.2	
P1	1.53	P7	1.55
P2	1.36	P8	1.67
P3	1.63	P9	1.51
P4	1.33	P10	1.79
P5	1.61	P11	1.78
P6	1.37	P12	1.85

In AESR 6.3, the highest SQI (Table 6) was obtained in P3 (1.63) and the lowest in P4 (1.33) whereas in case of AESR 10.2, the highest SQI was obtained in P12 (1.85) and the lowest in P9 (1.51). In both the AESRs, the relation between SQI and average yield (Figure 2 and Figure 3) was found to be linear and the mathematical expression was y = 31.5x – 19.7, R^2= 0.863** for AESR 6.3. For AESR 10.2, it was y= 24.41x – 10.35 and the correlation between SQI and average yield was R^2= 0.19. However, when P6 was considered as an outlier, their mathematical expressions were y = 28.33x – 13.28 and R^2 value improved from 0.19 to 0.79. Hence average yield can also be used as an alternative indicator of soil quality evaluation in terms of crop performance.

Pedon 11 (AESR 10.2) having high residual value is considered as an outlier while developing the relationship between SQI and average yield. In case of the outlier, inspite of SQI being high, the crop performs poorly. Hence, it might be interpreted from the result that proper management is lacking in this outlier soil profile to deliver optimum yield and hence site specific management must be improved at this site.

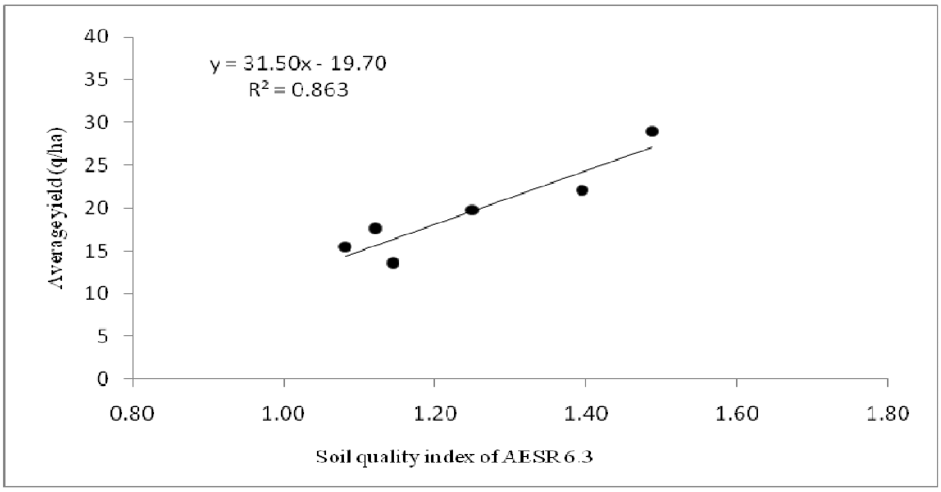

Figure 2: Relation between Soil Quality Index (SQI) and Yield of AESR 6.3

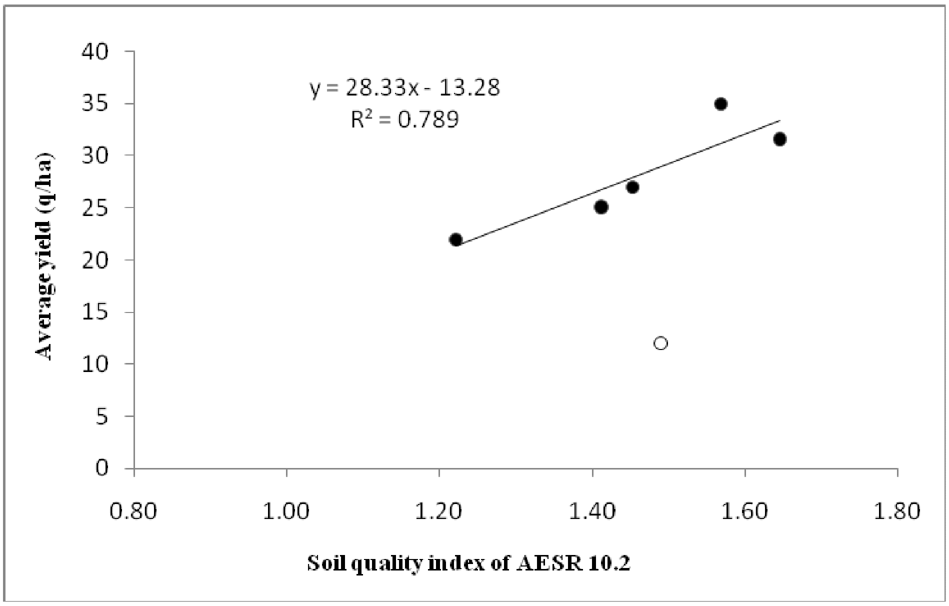

Figure 3: Relation between Soil Quality Index (SQI) and Yield of AESR 10.2

CONCLUSIONS

In case of large datasets, use of Pearson's correlation followed by principal component analysis was found to be an effective data reduction tool. This facilitated identification of minimum datasets of physical, chemical and biological indicators for proper soil quality assessment. The successful application of this method in SQ assessment provides us to suggest that whenever we have such datasets for similar agro-ecological conditions, we can compute soil quality indices by using this method for assessing and monitoring soil quality**.** Once this is done, these soil quality indices could be effectively used to determine the future course of action for sustaining and improving the quality of soils.

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